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THE BALLUTE: A RETARDATION DEVICE AND WIND SENSOR

By

James K. Luers

University of Dayton
Research Institute
Dayton, Ohio

Contract AF 19(628)-4796
Task No. 6682
Project No. 668204
Work Unit No. 66820401

Scientific Report No. 3

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Contract Monitor: Robert W. Lenhard
Aerospace Instrumentation Laboratory

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Prepared for

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ABSTRACT

Experimental tests have been made with various configurations of the BALLUTE in order to develop a stable retardation device for meteorological rocketsondes. This report discusses the reduction and analysis of these tests. Several of the BALLUTE configurations are shown to satisfy the project goal of providing the required stability as well as a sufficiently slow fall velocity to accurately measure winds and temperature.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I

INTRODUCTION

Two types of BALLUTE configurations are presently being tested and evaluated as retardation devices for Meteorological Rocketsondes. The two configurations are the 8 or 12-gore, 14-16 foot diameter BALLUTEs designed for use with the Arcasonde meteorological package and the light weight 4, 6, or 12-gore, 6-7 foot diameter BALLUTEs designed to be used with the Loki-Dartsonde package.

The mission of both BALLUTE configurations is to provide a stable retardation of the sonde during its descent from rocket apogee (approximately 200,000 ft) to 80,000 feet. Freedom from large coning angles experienced with the more conventional silk parachutes will result in cleaner telemetry reception. A slower fall rate is also desirable since it will allow the BALLUTE more time to sense the atmosphere and thus temperature and winds can be measured to a higher degree of accuracy. In order to attain these objectives design requirements demand that the BALLUTE be aerodynamically a very stable object and further that its fall velocity be sufficiently slow. Sufficiently slow is taken to mean a maximum vertical velocity of 300 ft/second at 180,000 feet or a ballistic coefficient value of $W/C_D A = 0.50$. Slower fall rates are, of course, desirable.

SECTION II

LOG OF FLIGHTS

BALLUTE Arcasonde and Dartsonde flights began in April of 1966 at Cape Kennedy. A log of the successful flights and their characteristics are given in Table 1.

TABLE 1

BALLUTE CHARACTERISTICS														
Flight Number	Type of Flight	Time Zulu	Flight Date	Ballute Series	Size Diam. ft.	Gage	Gores Sides	Fence		Front Area ft^2	Inlet Area in^2	Ballute Weight lbs.	Sonde Weight lbs.	Total Weight lbs.
								Sides	% H					
3084	Ballute	1606	04-22-66	Dart 2	6	1/4	12	6	12	31	86	.314	.74	1.05
2643	Ballute	1500	05-24-66	Dart 3	6	1/4	12	6	12	31	86	.32	.74	1.06
2561	Ballute	1838	05-26-66	Dart 4	6	1/4	12	6	12	31	86	.32	.75	1.07
2793	Ballute	1445	05-27-66	Dart 5	6	1/4	12	6	12	31	86	.32	.75	1.07
0906	Ballute	1615	07-06-66	Dart 7	6	1/4	6	6	12	33	130	.32	.78	1.10
0715	Ballute	1509	07-08-66	Arcas 6	16	1/4	12	6	12	221.7	300	2.43	4.63	7.06
7683	Parachute	1630	07-08-66											
7391	Ballute	1500	08-15-66	Arcas 9	12 1/2	1/2	12	6	12	135	86	3.08	4.63	7.71
5554	Ballute	1500	08-16-66	Arcas 10	14	1/2	12	6	12	169.7	110	3.27	4.63	7.90
6097	Parachute	1600	08-16-66											
7867	Ballute	1500	08-18-66	Arcas 11	14	1/2	12	6	12	169.7	110	3.24	4.63	7.87
2419	Parachute	1359	09-14-66											
2691	Ballute	1830	09-14-66	Arcas 12	14	1/2	12	6	12	169.7	121	3.18	3.3	6.48
3163	Ballute	1600	09-15-66	Arcas 13	14	1/2	12	6	12	169.7	121	3.17	3.3	6.47
1947	Ballute	1500	09-19-66	Arcas 14	15	1/2	12	6	12	194.8	121	3.54	4.63	8.17
1731	Ballute	1500	09-20-66	Arcas 15	15	1/2	12	6	12	194.8	121	3.54	4.63	8.17
3309	Parachute													
4765	Ballute	1900	11-14-66	Dart 11	6 1/2	1/4	4	4	20	42.25	125	.357	.74	1.097
3166	Ballute	2007	11-14-66	Dart 12	6	1/4	6	6	12	33	130	.316	.74	1.056
6258	Ballute	1520	11-15-66	Dart 13	6 1/2	1/4	4	4	20	42.25	125	.357	.74	1.097
4287	Ballute	1920	11-17-66	Arcas extra	15	1/2	12	6	12	194.8	121	3.48	3.3	6.78
3729	Ballute	1830	11-18-66	Arcas extra	15	1/2	12	6	12	194.8	121	3.40	3.3	6.7
2577	Ballute	1430	01-30-66	Arcas 16	15	1/2	8	8	20	170	65	3.30	4.63	7.93
0015	Ballute	1703	01-30-67	Dart 15	6 1/2	1/4	4	4	20	42.25	125	.44	.74	1.18
2694	Ballute	1500	01-31-67	Arcas 17	15	1/2	8	8	20	170		3.26	4.63	7.89
0099	Ballute	1608	01-31-67	Dart 16	6 1/2	1/4	4	4	20	42.25	125	.34	.74	1.08
1616	Ballute	1500	02-27-67	Dart 17	7	1/4	4	4	20	49	125	.38	.74	1.12
0613	Ballute	1630	02-28-67	Dart 18	7	1/4	4	4	20	49	125	.38	.74	1.12
0776	Ballute	1500	03-01-67	Arcas 18	15 1/2	1/2	8	8	20	170		3.33	4.63	7.96
7092	Ballute	1600	03-02-67	Arcas 19	15 1/2	1/2	8	8	20	170		3.36	4.63	7.99
3605	Ballute	1500	04-12-67	Arcas 20	15 1/2	1/2	8	8	20	170		3.34	4.63	7.97
0739	Ballute	1500	04-19-67	Arcas 21	15 1/2	1/2	8	8	20	170		3.34	4.63	7.97
5395	Ballute	1421	05-09-67	Dart 21	7	1/4	4	4	20	49	125	.35	.74	1.09
8990	Ballute	1500	05-10-67	Arcas 22	15 1/2	1/2	8	8	20	170		3.01	4.63	7.64
8622	Ballute	1600	05-10-67	Arcas 23	15 1/2	1/2	8	8	20	170		3.01	4.63	7.64
8767	Ballute	1527	05-12-67	Dart 23	7	1/4	4	4	20	49	125	.35	.74	1.09
6513	Ballute	1627	05-12-67	Dart 24	7	1/4	4	4	20	49	125	.35	.74	1.09
8534	Ballute	1115	05-18-67	Dart 25	7	1/4	4	4	20	49	125	.35	.74	1.09

SECTION III

DATA REDUCTION

The data from the successful flights were reduced at UDRI. The reduced data were presented in the form of a blue data booklet for each flight. The format of the booklet and what it contains follow.

Title Page -- Contains launch and flight log information as well as any special comments concerning performance of the sonde and radars.

Tabulations -- As many as five (5) sets of tabulations may be contained in a booklet if all temperature information is available. The first tabulation gives the component velocity and acceleration of the BALLUTE as obtained by a 39-7 linear linear least squares fit. The second tabulation computes the ballistic coefficient using the temperature from the strip chart, and the vertical velocity obtained from the first tabulation. The remaining tabulations contain the rawinsonde flight of the day and the Cape Kennedy BALLUTE reduction of winds and density.

Plots -- If temperature data is available, three types of plots are presented in the booklets; a) vertical velocity vs altitude, b) temperature vs altitude, and c) density vs altitude. If the temperature trace is poor or not available only the vertical velocity vs altitude plot is included.

Table 2 shows the content of each data booklet that was reduced by UDRI.

TABLE 2

BALLUTE DATA BOOKLETS

Flight Number	Type of Flight	Time Zulu	Flight Date	Ballute Series	Velocity Acceleration Data From Radar		Cape Kennedy Reduction			
							Temperature and Density Plots	Winds	Temperature	Rawinsonde
3084	Ballute	1606	04-22-66	Dart 2		19.18	X	X		
2643	Ballute	1500	05-24-66	Dart 3	1.16		X	X		
2561	Ballute	1838	05-26-66	Dart 4	1.16		X	X		X
2793	Ballute	1445	05-27-66	Dart 5	1.16		X			
0906	Ballute	1615	07-06-66	Dart 7	1.16	1.4	X			X
0715	Ballute	1509	07-08-66	Arcas 6	1.16	1.3	X	X	X	X
7683	Parachute	1630	07-08-66		1.16	1.4		X		
7391	Ballute	1500	08-15-66	Arcas 9	1.16		X	X	X	X
5554	Ballute	1500	08-16-66	Arcas 10	1.16		X		X	X
6097	Parachute	1600	08-16-66		1.16		X	X	X	X
7867	Ballute	1500	08-18-66	Arcas 11		19.18	X		X	X
2419	Parachute	1359	09-14-66		1.16					X
2691	Ballute	1830	09-14-66	Arcas 12	1.16		X		X	X
1615	Parachute	1359	09-15-66		1.16	1.3				X
3163	Ballute	1600	09-15-66	Arcas 13	1.16	1.4	X			X
1947	Ballute	1500	09-19-66	Arcas 14	1.16	1.3	X		X	X
1731	Ballute	1500	09-20-66	Arcas 15	1.16		X		X	
3309	Parachute				1.16					
4765	Ballute	1900	11-14-66	Dart 11	1.16	1.5				X
3166	Ballute	2007	11-14-66	Dart 12	1.16	1.5				X
6258	Ballute	1520	11-15-66	Dart 13	1.16					
4287	Ballute	1920	11-17-66	Arcas	1.16	1.4	X		X	X
3729	Ballute	1830	11-18-66	Arcas	1.16	1.4				
2577	Ballute	1430	01-30-67	Arcas 16	1.16	1.4				
0015	Ballute	1703	01-30-67	Dart 15	1.16	1.4				
2694	Ballute	1500	01-31-67	Arcas 17	1.16	Mod II				
0099	Ballute	1608	01-31-67	Dart 16	1.16	Mod II				
1616	Ballute	1500	02-27-67	Dart 17	1.16	Mod II				
0613	Ballute	1630	02-28-67	Dart 18	1.16					
0776	Ballute	1500	03-01-67	Arcas 18	1.16	Mod II				
7092	Ballute	1600	03-02-67	Arcas 19	1.16	1.5				
3605	Ballute	1500	04-12-67	Arcas 20	1.16	Mod II	X	X	X	X
0739	Ballute	1500	04-19-67	Arcas 21	1.16	1.5	X	X	X	X
5395	Ballute	1421	05-09-67	Dart 21		1.5	X	X	X	X
8990	Ballute	1500	05-10-67	Arcas 22		1.5	X	X	X	X
8622	Ballute	1600	05-10-67	Arcas 23		1.5		X		X
8767	Ballute	1527	05-12-67	Dart 23	1.16	1.5	X	X	X	X
6513	Ballute	1627	05-12-67	Dart 24	1.16	1.5	X	X	X	X
8534	Ballute	1115	05-18-67	Dart 25	1.16	1.5	X	X	X	

SECTION IV

METHOD OF REDUCTION

4.1 Velocity and Acceleration of Ballute

The velocity of the BALLUTE was obtained by a linear least squares fit of 39-1/2 second position points. The slope of the fitted line is called the velocity at the midpoint in time of the interval. If the radar records at increments less than 1/2 second then these position points are averaged to obtain 1/2 second increments between consecutive coordinates. To obtain an acceleration, seven (7) velocities are fitted linearly and the slope assigned to the midpoint as the acceleration. To obtain derivatives each second one slides two position coordinates and one velocity coordinate and repeats the fitting procedure. For a further description see Engler 1965.

4.2 Temperature

Temperature was either read directly from the strip chart or if it had already been reduced it was interpolated from the reduced data at altitude increments of 1000 feet.

4.3 Density

The density was calculated from temperature by using the Gas Law and Hydrostatic Equation. The formula is

$$\ln(\rho_n) = \ln(\rho_0) - \ln\left(\frac{T_n}{T_0}\right) - \frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dz \quad \text{(See Appendix)} \qquad (1)$$

where ρ_0 = initial density - obtained from rawinsonde flight for the day

T = Temperature

K = Gas constant/molecular weight of atmosphere

g = gravitational acceleration

The integration started with the lowest BALLUTE altitude and proceeded upwards so that the initial density (ρ_0) could be taken from the rawinsonde flight for that day.

4.4 Ballistic Coefficient

The ballistic coefficient is computed from the equation

$$q = \frac{\rho \dot{Z}^2}{2}$$

where q = ballistic coefficient

$\dot{Z}$ = vertical velocity.

SECTION V

ANALYSIS

5.1 Wind

Computation of horizontal winds has not been included in the present reduction of BALLUTE flights. The following analysis is designed to determine the necessity and importance of the acceleration and apparent mass of the BALLUTE in a wind computation.

Ignoring the Coriolis force and the buoyancy of the payload, the equations of motion in the X and Z direction for the BALLUTE can be written as:

$$(m_p + m_g)\ddot{X} = \frac{1}{2}\rho C_D AV(W_x - \dot{X}) + m'(\dot{W}_x - \ddot{X}) \qquad (2)$$

$$(m_p + m_g)\ddot{Z} = \frac{1}{2}\rho C_D AV(W_z - \dot{Z}) + m'(\dot{W}_z - \ddot{Z}) - m_p|g| \qquad (3)$$

where

m_p = mass of BALLUTE plus payload

m_g = mass of gas

m' = apparent mass of BALLUTE

C_D = Drag Coefficient

A = Cross sectional area of BALLUTE

$$V = \left[(\dot{X} - W_x)^2 + (\dot{Z} - W_z)^2\right]^{1/2}$$

Assuming the absence of vertical winds, Equation (2) and (3) are combined to give the wind equation:

$$W_x - K_2\dot{W}_x = \dot{X} - K_1\ddot{X} \qquad (4)$$

where

$$K_1 = \frac{(m_p + m_g + m')\dot{Z}}{(m_p + m_g + m')\ddot{Z} + m_p|g|} \qquad K_2 = \frac{m'\dot{Z}}{(m_p + m_g + m')\ddot{Z} + m_p|g|}$$

If the wind equation is written as $W_x = \dot{X} - K_1 \ddot{X} + K_2 \dot{W}_x$ then the component terms on the right hand side of this equation can be plotted for a given wind field to determine their contribution to W_x. The term: $\dot{X}$ represents the velocity of the BALLUTE; $K_1\ddot{X}$ represents the contribution to W_x as seen by the acceleration of the BALLUTE; and $K_2\dot{W}_x$ represents the contribution to W_x due to the apparent mass of the BALLUTE.

Consider a Sinusoidal Wind Field

Figures 1-4 are plots of the component terms of the wind equation for the wind field $W_x = A \sin(\frac{2\pi Z}{2000})$. From the plots it is seen that the term $K_2 \dot{W}_x$ contributes less than 1/2% to the amplitude. K_2, however, was computed using $m' = 1/2\ \rho$ Vol which is the apparent mass formula for a sphere. This assumption was necessary due to the lack of knowledge concerning the apparent mass of the BALLUTE. Even if the formula were considerably in error the apparent mass term would still not be a significant term in the wind equation. The acceleration term $K_1\ddot{X}$, however, is significant, particularly at high altitudes. It is also seen from the plots that the Dartsonde BALLUTE is slightly more wind sensitive than the Arcasonde BALLUTE. This is due to its slower fall velocity and smaller ballistic coefficient (see Table 3).

Consider a Linear Wind Field

The sensing ability of the BALLUTE can also be analyzed under the influence of a linear wind field. Figures 5 and 6 compare Arcasonde BALLUTE velocity to wind velocity for linear winds with shear values from .013 to .1 per sec. In all cases, BALLUTE velocity is not an accurate measure of wind velocity and consequently the acceleration of the BALLUTE must be included in any wind computation. It can easily be shown that the apparent mass term is insignificant for a linear wind field as well as for a sinusoidal field.

Hence accurate winds can be determined only if velocity and accelerations are measured accurately. Initially, velocity and acceleration have been obtained from the 39-7 linear fit. This technique was used as a result of our previous experience with the ROBIN system taking into consideration the slower vertical velocity of the BALLUTE by lengthening the position smoothing interval from 31 to 39 points. It is not believed that this will ultimately be the smoothing technique decided upon to compute velocities and accelerations and thus calculate a wind. Indications are that the vertical smoothing interval should not necessarily be of the same length as the horizontal. Also in some cases a cubic velocity fit may improve upon a linear fit.

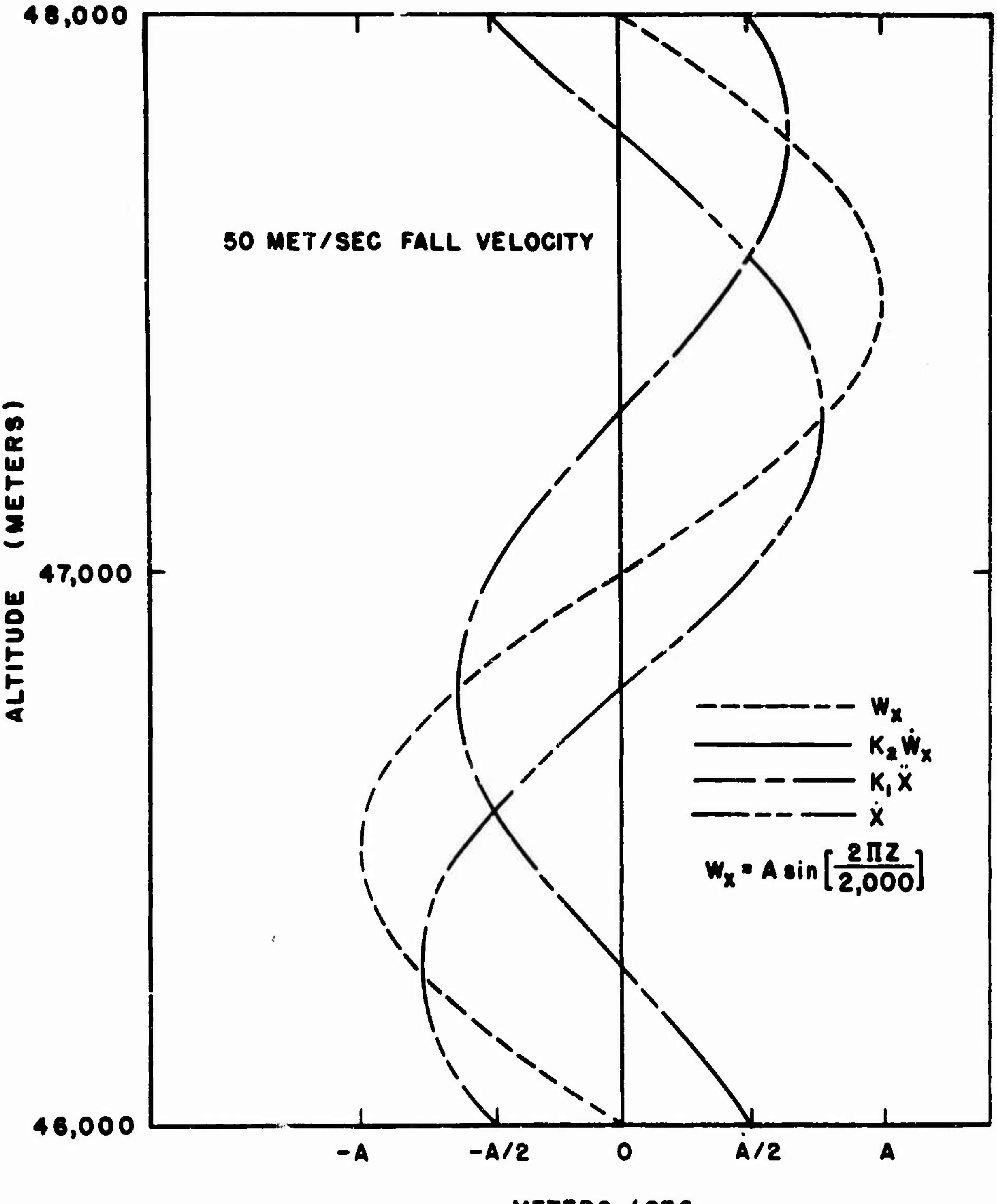


Figure 1. Response of Arcasonde BALLUTE to Sinusoidal Wind Field

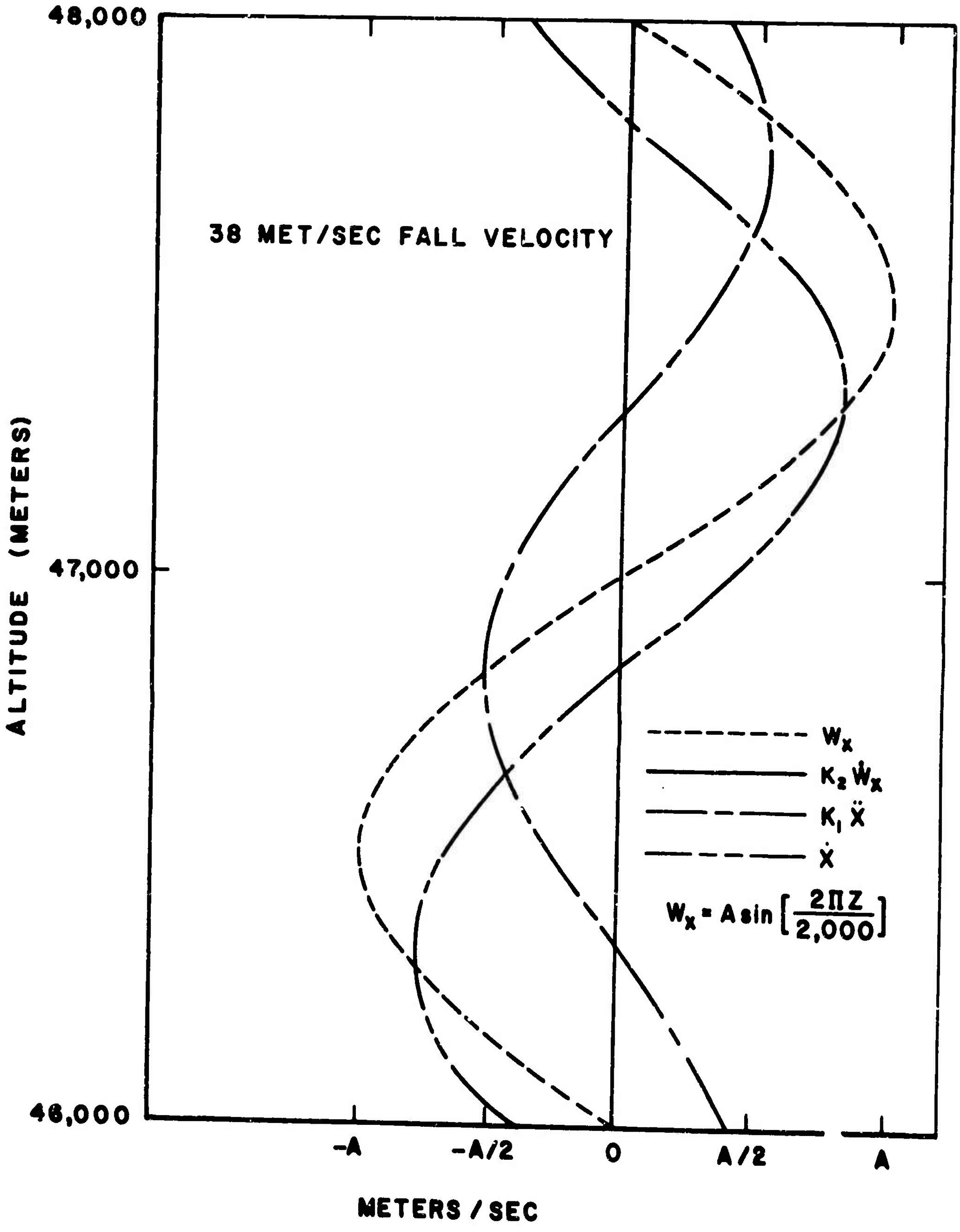


Figure 2. Response of Dartsonde BALLUTE to Sinusoidal Wind Field

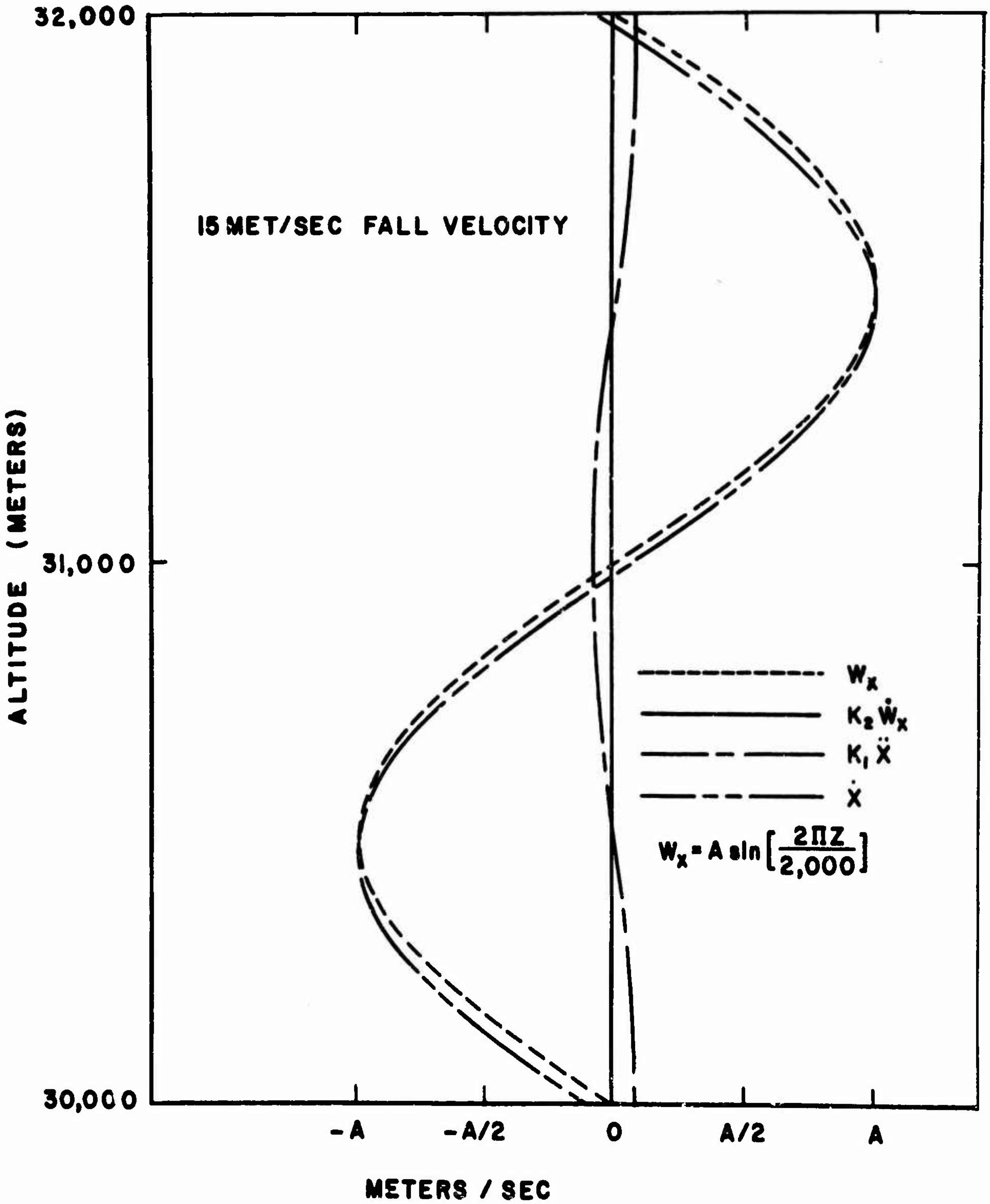


Figure 3. Response of Arcasonde BALLUTE to Sinusoidal Wind Field

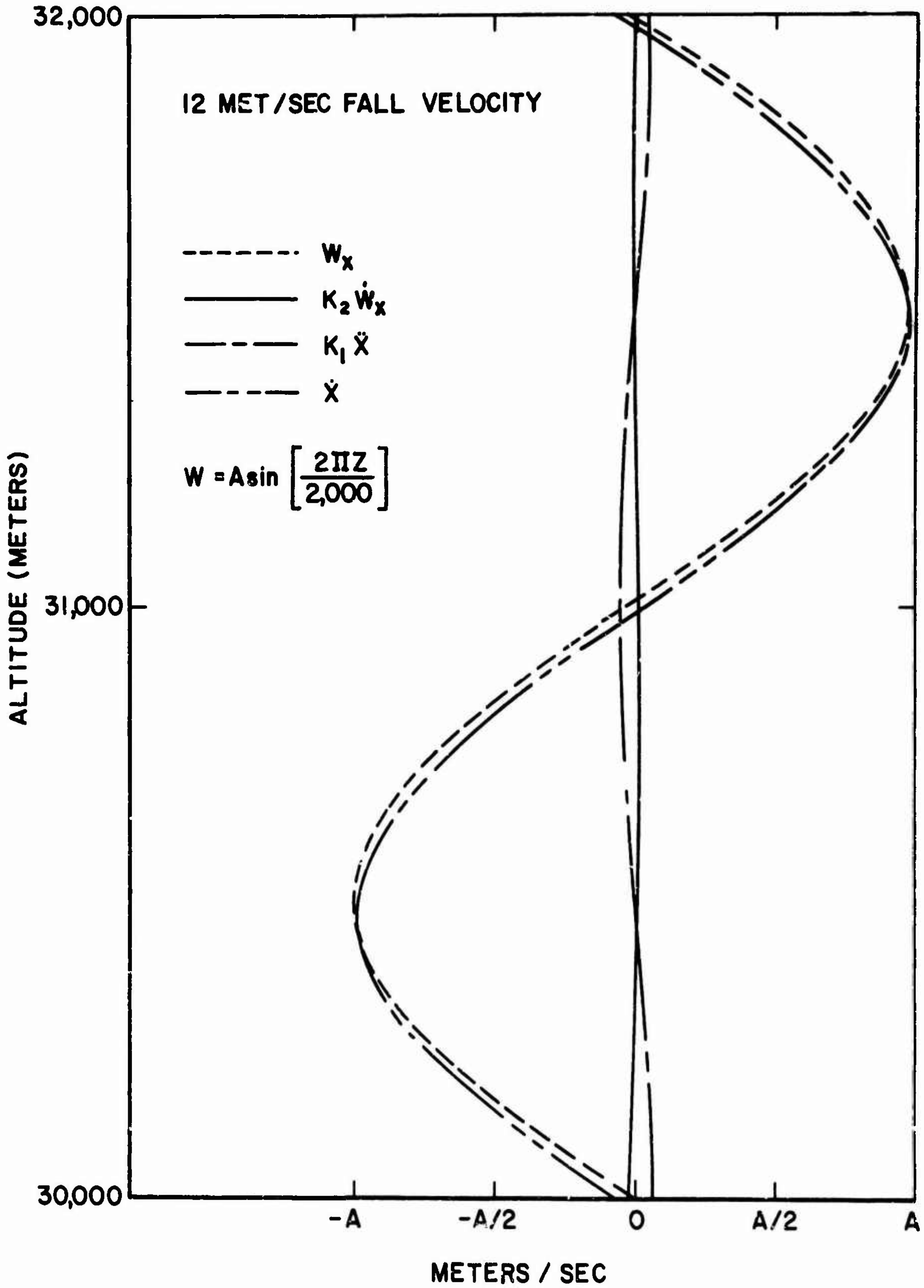


Figure 4. Response of Dartsonde BALLUTE to Sinusoidal Wind Field

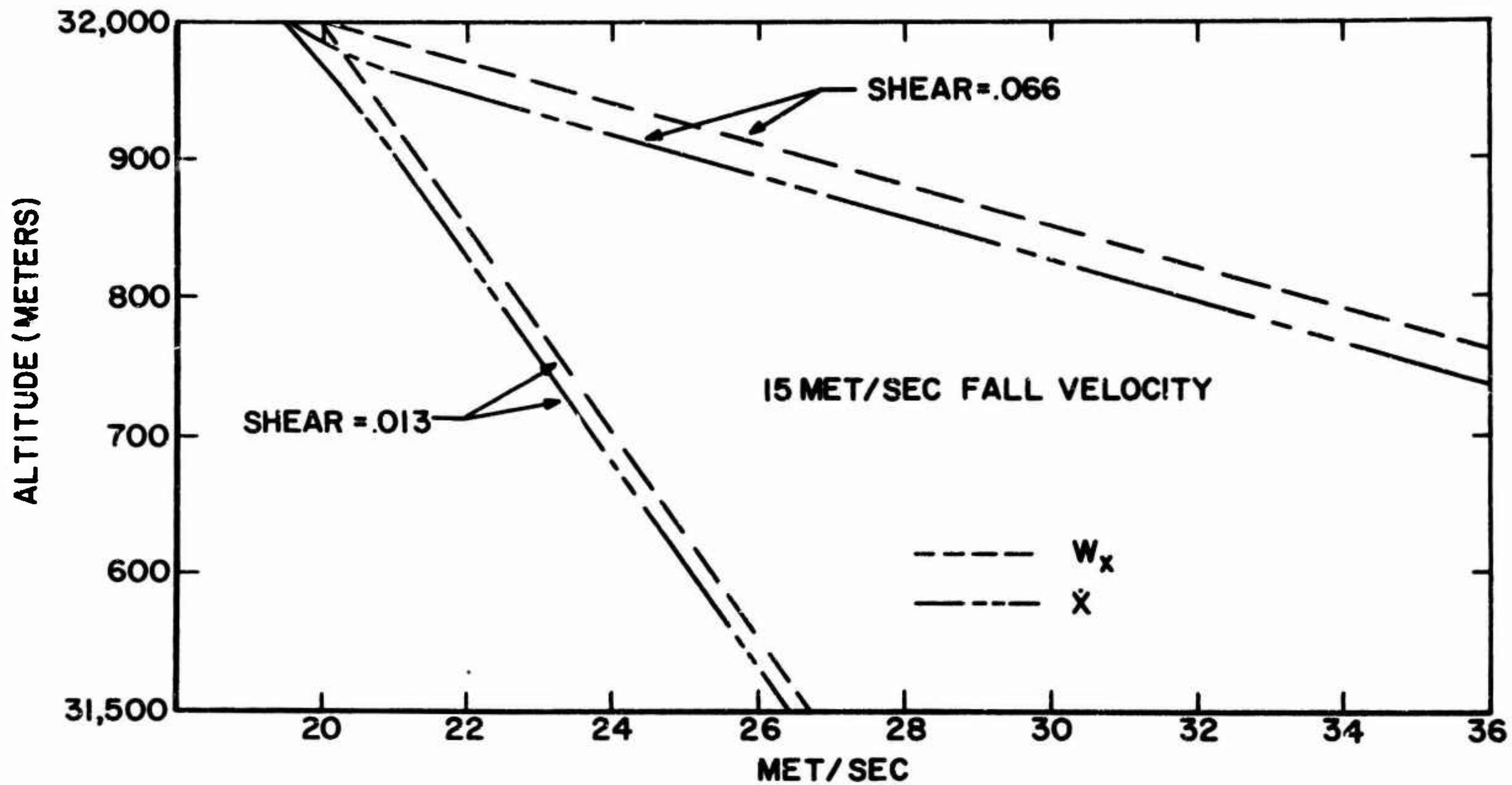


Figure 5. Response of Arcasonde BALLUTE to Linear Wind Field

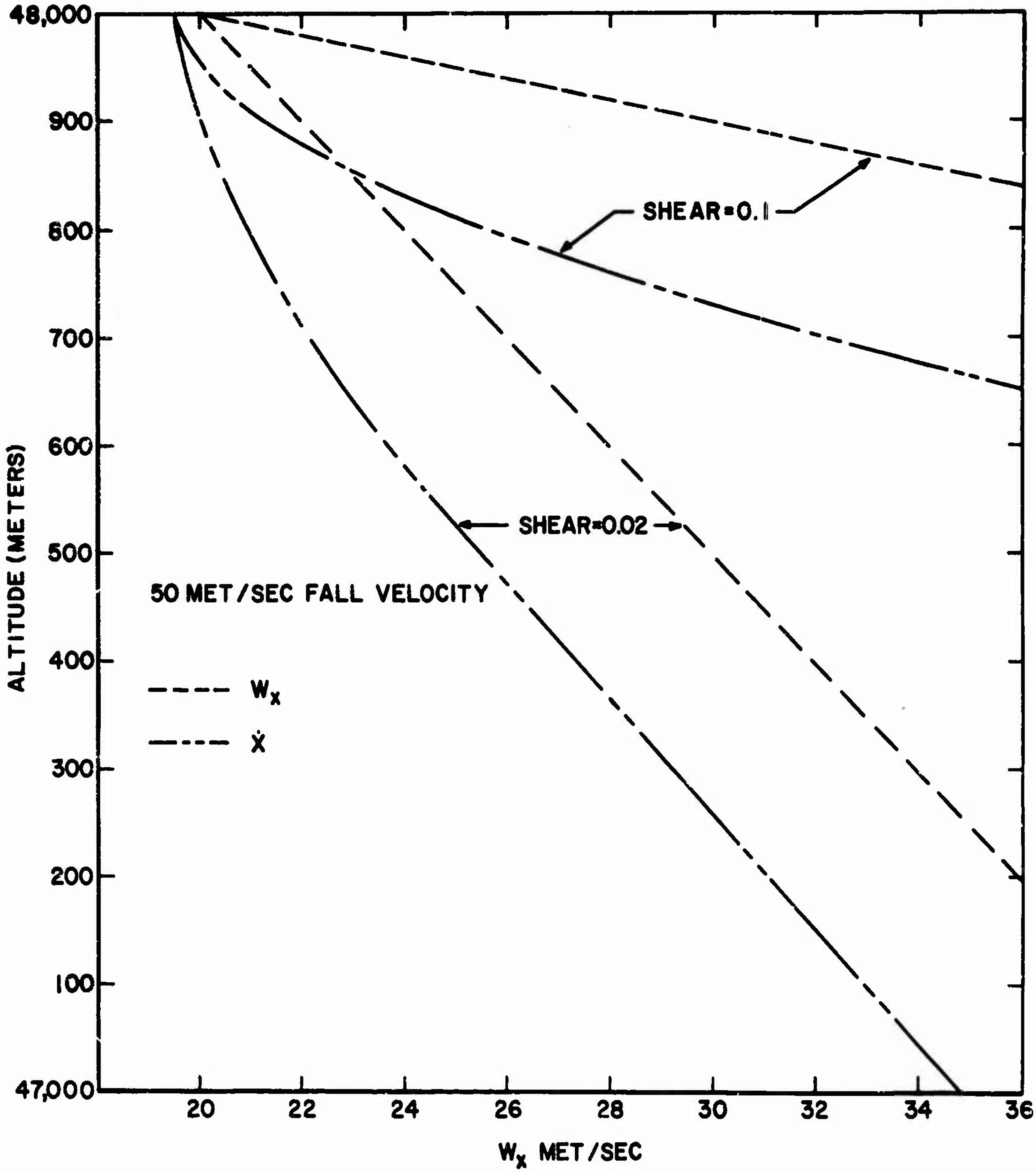


Figure 6. Response of Arcasonde BALLUTE to Linear Wind Field

5.2 Ballistic Coefficient

In order to insure an acceptable fall rate the BALLUTE has a design criterion of maintaining a maximum ballistic coefficient of $q = \frac{W}{C_D A} = 0.050$. The ballistic coefficient equation is derived from the vertical equation of motion as follows:

$$(m_p + m_g)\ddot{Z} = \frac{1}{2}\rho C_D AV (W_z - \dot{Z}) + m' (\dot{W}_z - \ddot{Z}) - m_p |g|$$

If over a sufficiently small interval $\dot{Z}$ can be considered constant and $W_z = 0$ the equation simplifies to:

$$\frac{m_p |g|}{C_D A} = -\frac{1}{2} \rho V \dot{Z}. \qquad (5)$$

The common formula for ballistic coefficient

$$q = \frac{m_p |g|}{C_D A} = \frac{1}{2} \rho \dot{Z}^2 \qquad (6)$$

is obtained by further assuming that $V = \dot{Z}$. This assumption is valid except for the first 3000 feet of descent. During this period the BALLUTE has a large horizontal velocity transmitted to it from the rocket, and thus its velocity relative to the air may be much larger than $\dot{Z}$.

In the data booklets two methods have been used to evaluate q.

<u>Method 1</u>

From the thermistor temperature trace the density is computed by Equation (1), $\dot{Z}$ is obtained from the 39-7 linear fit, and q is then computed as $q = \frac{1}{2} \rho \dot{Z}^2$. A ballistic coefficient is computed by this method at each 1000 feet of altitude.

<u>Method 2</u>

The second method of calculating a ballistic coefficient assumes that the BALLUTE fell in the 1962 Standard Atmosphere. For a given ballistic coefficient (q) a $\dot{Z}$ vs Z curve is generated from Equation (3) by obtaining density as a function of altitude from the 1962 Standard Atmosphere. A series of these $\dot{Z}$ vs Z curves are generated for values of q from q = 0.01 to q = 0.10.

From a reduced BALLUTE flight a plot is made of $\dot{Z}$ vs Z. This velocity profile of the BALLUTE is then compared to the ballistic coefficient curves. The curve that most closely follows the BALLUTE velocity profile is considered a representative value for q. It has been experimentally varified by both Method 1 and Method 2 that the value of q is relatively constant over the entire flight. If the atmosphere is not model an error will be made using Method 2 to compute a ballistic coefficient. For example if density is only 80% of Model, then

$$q_{True} = \frac{1}{2} (0.8 \rho_{Model}) \dot{Z}^2$$

$$q_{Method\ 2} = \frac{1}{2} (\rho_{Model}) \dot{Z}^2$$

$$\%_{Error} = \frac{|q_{True} - q_{Method\ 2}|}{q_{True}} = \frac{\frac{1}{2} (0.2 \rho_{Model}) \dot{Z}^2}{\frac{1}{2} (0.8 \rho_{Model}) \dot{Z}^2} = 25\% .$$

Table 3 gives the ballistic coefficient for each flight as determined by both methods. The 12-gore Dartsonde BALLUTEs show a somewhat smaller ballistic coefficient (.045) than the 12-gore Arcasonde BALLUTEs (.05). However, a later series of firing using a 4-gore Dartsonde BALLUTE and 8-gore Arcasonde BALLUTEs have produced a substantial decrease in the ballistic coefficient. An average value of ballistic coefficient for the 4-gore Dartsonde BALLUTE is 0.035 and the 8-gore Arcasonde BALLUTE 0.04. These ballistic coefficients provide the required descent rate.

5.3 Temperature

In order to insure an accurate measure of temperature, a) the vertical velocity of the BALLUTE must be sufficiently slow to insure that induced aerodynamic heating is negligible and b) the BALLUTE is aerodynamically a stable vehicle so that the system does not oscillate or come through wide angles thus resulting in aerodynamic heating of the thermistor as well as signal dropouts. The established vertical velocity criterion is to maintain a ballistic coefficient ≤ 0.05. As can be seen by Table 3, BALLUTEs achieve this result in nearly all cases. The stability condition has been verified by an observation of position plots as well as the temperature strip chart which shows very few signal dropouts. (See Wright and Graham, 1966.) Figures 7-12 are North-East position plots of flight 906. Throughout the entire flight path there is no evidence of any periodic aerodynamic oscillation in the BALLUTE's path. The very smooth path prevalent over several large segments also substantiates the stability of the BALLUTE.

TABLE 3

BALLISTIC COEFFICIENTS

Flight Number	Type of Flight	Time Zulu	Flight Date	Ballute Series	Ballistic Coefficient Method 1	Ballistic Coefficient Method 2
3084	Ballute	1606	04-22-66	Dart 2		.05
2643	Ballute	1500	05-25-66	Dart 3	.035-.045	.045
2561	Ballute	1838	05-26-66	Dart 4	.04 -.05	.045
2793	Ballute	1445	05-27-66	Dart 5	.06 -.07	.065
0906	Ballute	1615	07-06-66	Dart 7	.035-.04	.04
1715	Ballute	1509	07-08-66	Arcas 6	.04 -.07	.04-.06
7683	Parachute	1630	07-08-66			.05-.07
7391	Ballute	1500	08-15-66	Arcas 9	.08 -.09	.08
5554	Ballute	1500	08-16-66	Arcas 10	.055-.065	.06
6097	Parachute	1600	08-16-66		.04 -.05	.055
7867	Ballute	1500	08-18-66	Arcas 11	.05 -.06	.055
2419	Parachute	1359	09-14-66			.04
2691	Ballute	1830	09-14-66	Arcas 12	.05 -.06	.05
1615	Parachute	1359	09-15-66			.05
3163	Ballute	1600	09-15-66	Arcas 13	.05	.05
1947	Ballute	1500	09-19-66	Arcas 14	.045-.05	.05
1731	Ballute	1500	09-20-66	Arcas 15	.05	.05
3309	Parachute					.05
4765	Ballute	1900	11-14-66	Dart 11		.04
3166	Ballute	2007	11-14-66	Dart 12		.045
6258	Ballute	1520	11-15-66	Dart 13		.035
4287	Ballute	1920	11-17-66	Arcas extra	.05 -.06	.05
3729	Ballute	1830	11-18-66	Arcas extra		.05
2577	Ballute	1430	01-30-67	Arcas 16		.06
0015	Ballute	1703	01-30-67	Dart 15		.05
2694	Ballute	1500	01-31-67	Arcas 17		.055
0099	Ballute	1608	01-31-67	Dart 16		.035
1616	Ballute	1500	02-27-67	Dart 17		.035
0613	Ballute	1630	02-28-67	Dart 18		.035
0776	Ballute	1500	03-01-67	Arcas 18		.015
7092	Ballute	1600	03-02-67	Arcas 19		.01-.1
3605	Ballute	1500	04-12-67	Arcas 20	.04 -.05	.04-.055
0739	Ballute	1500	04-19-67	Arcas 21	.04 -.05	.05
5395	Ballute	1421	05-09-67	Dart 21		
8990	Ballute	1500	05-10-67	Arcas 22	.04	.045
8622	Ballute	1600	05-10-67	Arcas 23		
8767	Ballute	1527	05-12-67	Dart 23	.025-.03	.025
6513	Ballute	1627	05-12-67	Dart 24	.025-.03	.03
8534	Ballute	1115	05-18-67	Dart 25	.035	.035

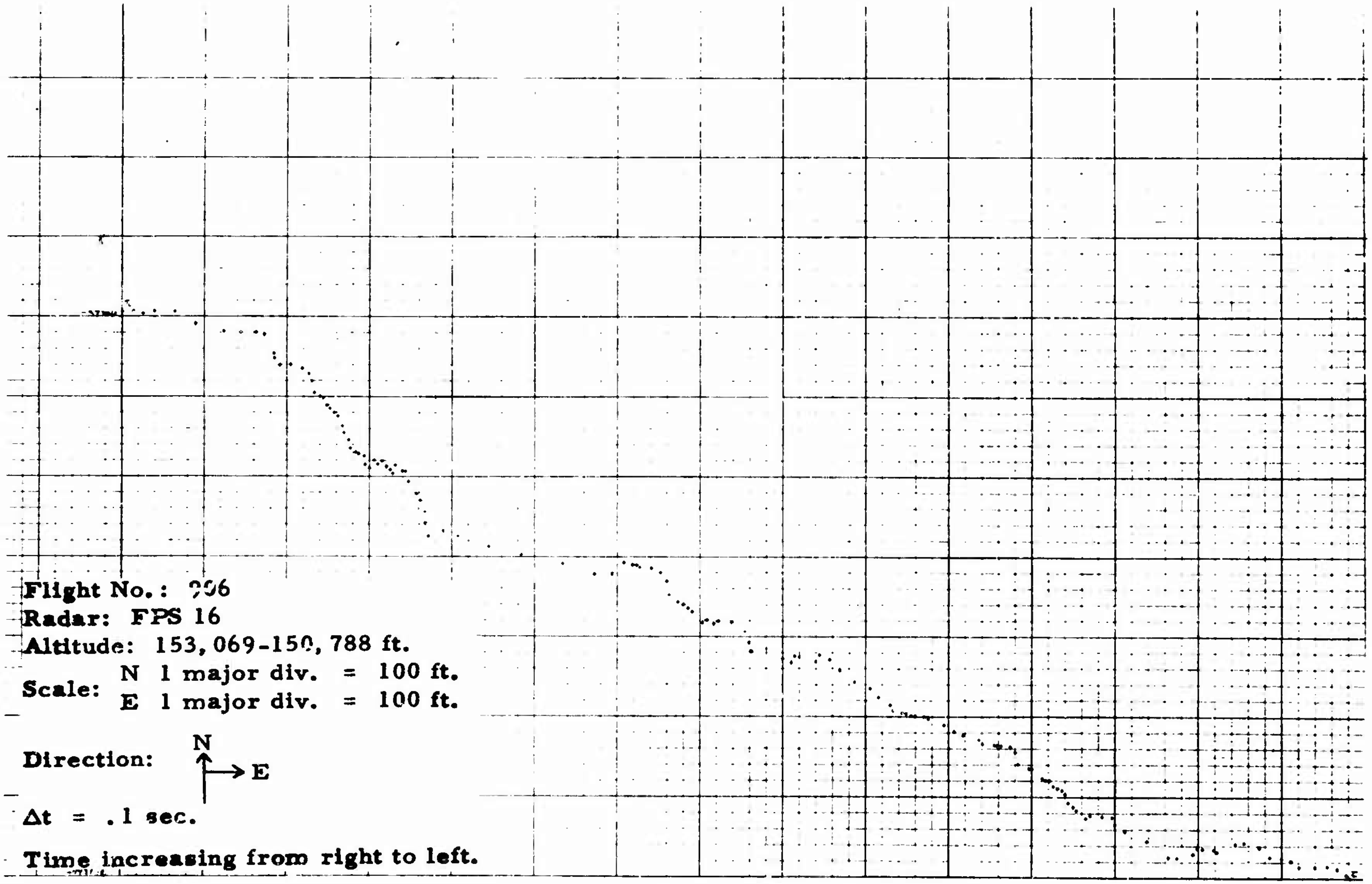
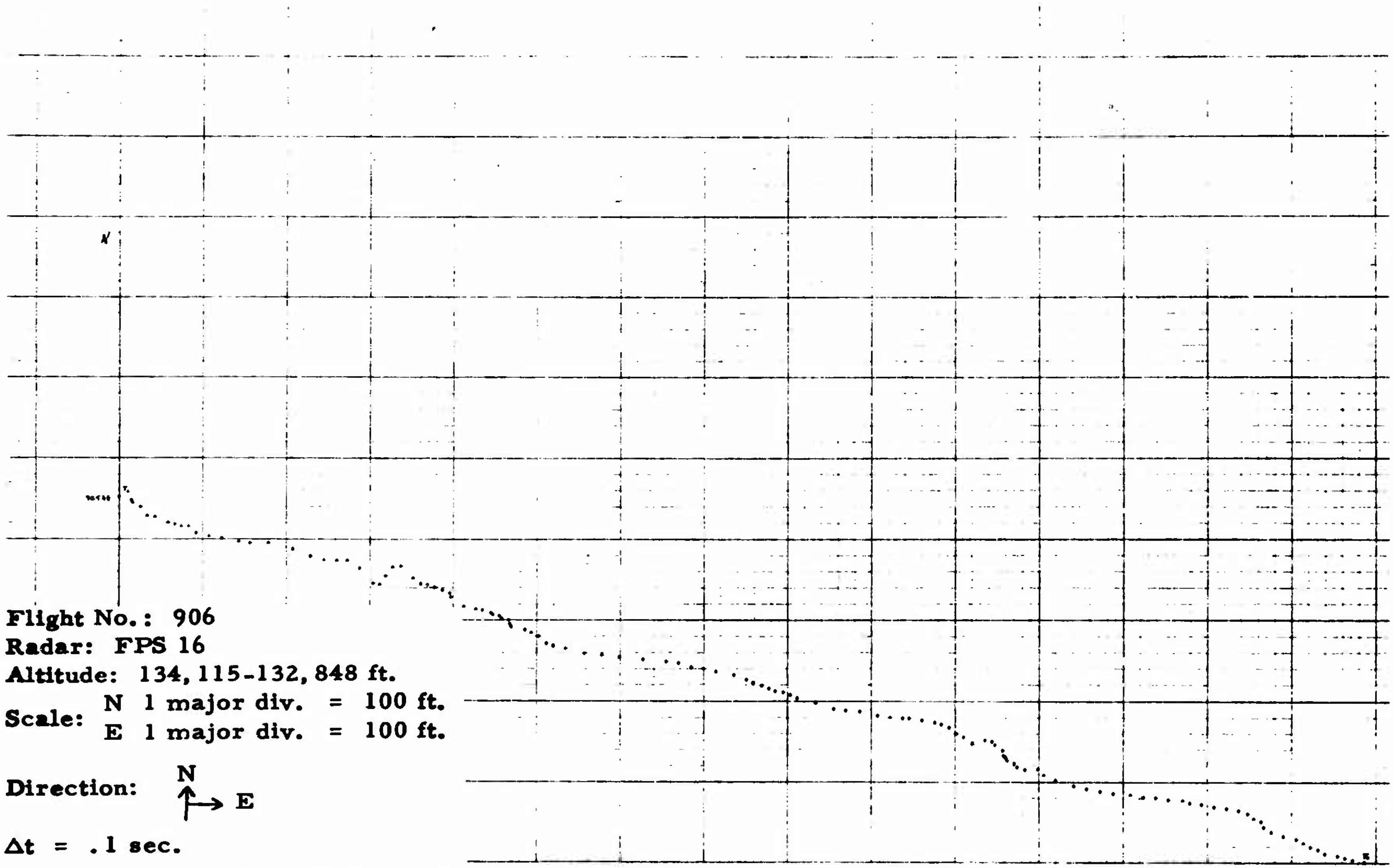


Figure 7. North vs East Position



Flight No.: 906
Radar: FPS 16
Altitude: 134,115-132,848 ft.
Scale: N 1 major div. = 100 ft.
E 1 major div. = 100 ft.

Direction: N ↑ → E

Δt = .1 sec.

Time increasing from right to left.

Figure 8. North vs East Position

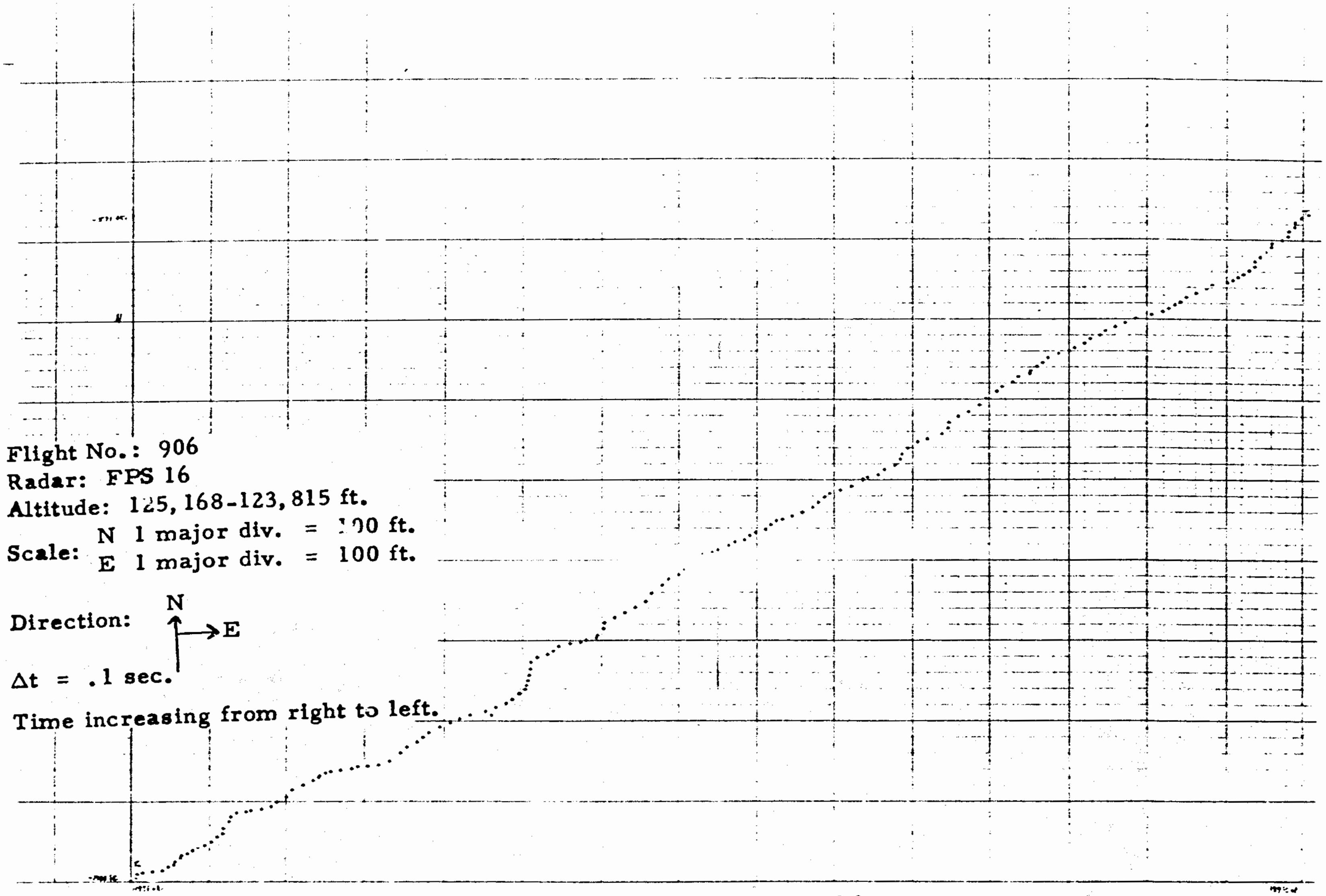


Figure 9. North vs East Position

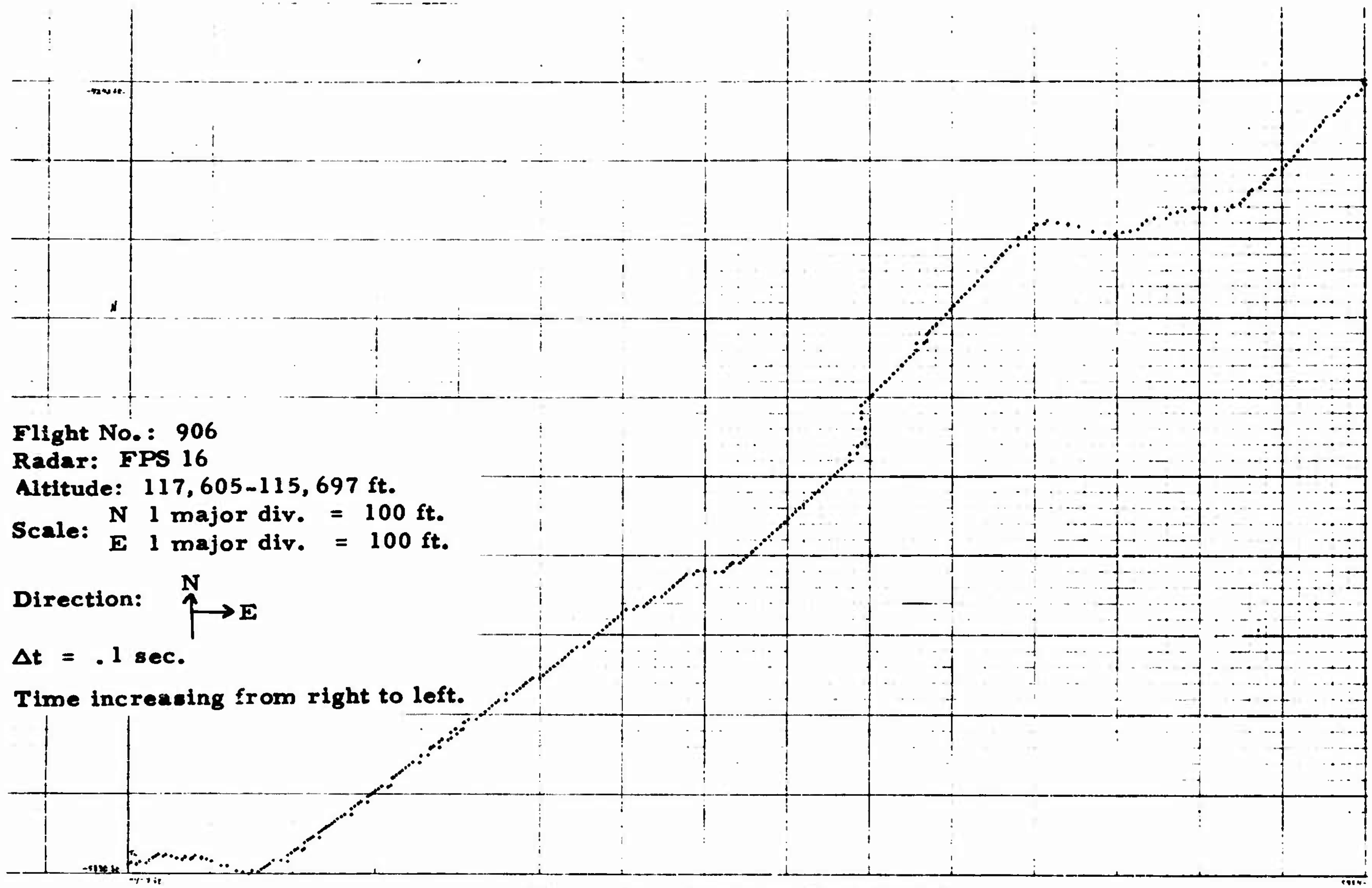
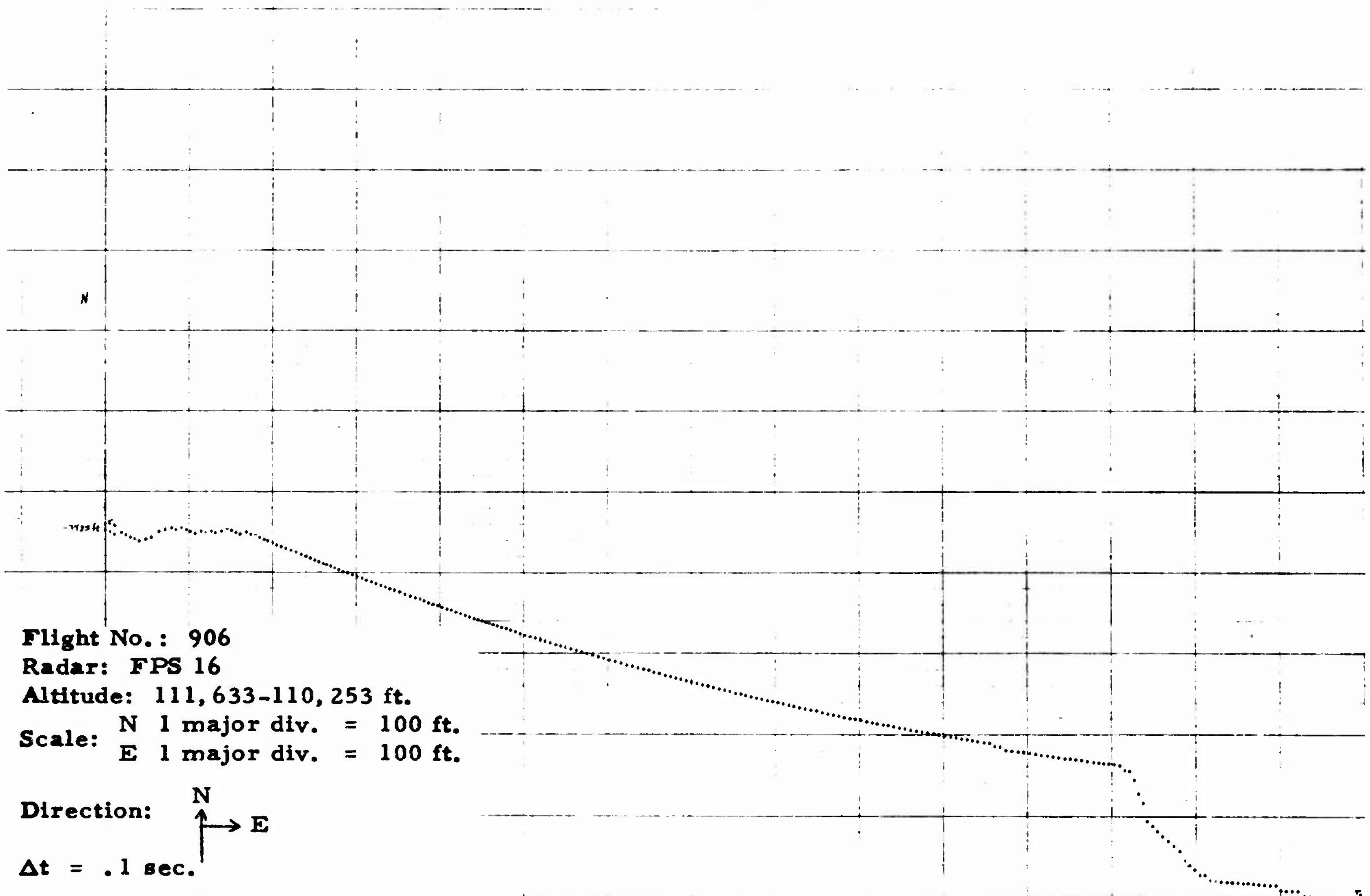


Figure 10. North vs East Position



Flight No.: 906
Radar: FPS 16
Altitude: 111,633-110,253 ft.
Scale: N 1 major div. = 100 ft.
E 1 major div. = 100 ft.

Direction: N ↑ → E

Δt = .1 sec.

Time increasing from right to left.

Figure 11. North vs East Position

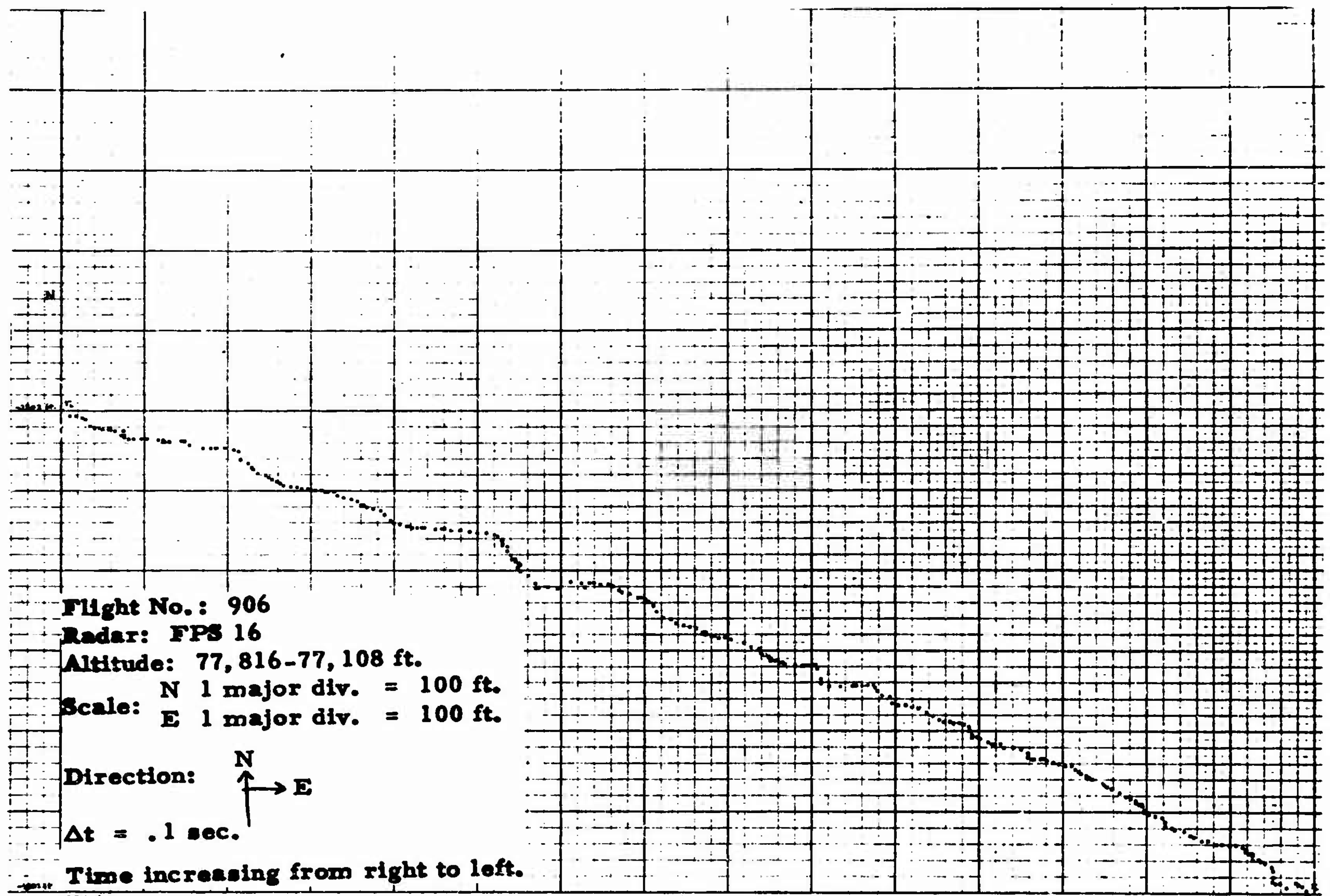


Figure 12. North vs East Position

5.4 Density

Density is obtained from temperature by use of Equation (1). The integral is evaluated by use of the trapezoidal rule (see Appendix). Integration by the trapezoidal rule assumes a linear interpolation of temperature between data points, which for the purposes of reduction were read every 1000 feet.

The initial density required for Equation (1) is obtained from the rawinsonde flight for the day of launch. If the initial density is in error by e_0 this will introduce a constant percentage error in density for the entire flight given by:

$$\% \text{ Error} = \frac{e_0}{\rho_0}. \quad \text{(See Appendix.)}$$

SECTION VI

CONTINUING INVESTIGATION OF BALLUTE AS WIND SENSOR

Future investigation at UDRI will be directed towards determining an optimum method to compute winds and the resulting error in winds as a function of radar error using this method. The UDRI is presently developing and evaluating smoothing methods for obtaining velocity and acceleration using the criterion of a minimization of the total error in the wind. The total error is defined as: $\sigma_T^2 = \sigma_{Fit}^2 + \sigma_{Noise}^2$ where σ_{Noise}^2 is the random error in wind due to the noise in the position coordinates and σ_{Fit}^2 is the bias error in wind introduced by the lack of fit of the smoothing function. The UDRI also is investigating the effect of the radar range resolver error on wind determination. Considerable work has already been done with regards to these two aspects on the High Altitude ROBIN, and ROSE systems. Much of this work can be applied to the BALLUTE system.

APPENDIX

DENSITY OBTAINED FROM A TEMPERATURE PROFILE

I.

1) $p = K \rho T$ Gas Law

2) $dp = -\rho |g| dZ$ Hydrostatic Equation

where

p = pressure

ρ = density

T = Temperature

g = gravitational acceleration

Z = Altitude

K = Universal Gas Constant/Molecular weight of atmosphere

From Equation (1)

$$dp = K \rho \, dT + KT \, d\rho$$

substituting into Equation 2 we get

$$-\rho |g| dZ = K \rho \, dT + KT \, d\rho.$$

Simplifing

$$\frac{d\rho}{\rho} = -\frac{|g|}{KT} dZ - \frac{dT}{T}$$

Initial Conditions:

At $Z = Z_0$, $g = g_0$, $T = T_0$, $\rho = \rho_0$

At $Z = Z_n$, $g = g_n$, $T = T_n$, $\rho = \rho_n$

Integrating down from the initial altitude Z_0 we get;

$$\int_{\rho_0}^{\rho_n} \frac{d\rho}{\rho} = -\int_{T_0}^{T_n} \frac{dT}{T} - \frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dZ$$

or

$$Ln\,(\rho_n) = Ln\,(\rho_0) - Ln\,(\frac{T_n}{T_0}) - \frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dZ$$

Assuming a linear interpolation of temperature between data points, the integral is evaluated by the trapezoidal rule.

$$Ln\,(\rho_n) = Ln\,(\rho_0) - Ln\,(\frac{T_n}{T_0}) -$$

$$- \frac{1}{2K}\left[(\frac{g_0}{T_0} + \frac{g_1}{T_1})(Z_1 - Z_0) + \ldots + (\frac{g_{n-1}}{T_{n-1}} + \frac{g_n}{T_n})(Z_n - Z_{n-1})\right]$$

II. Error Due to the Initial Guess of ρ_0

Let e_0 be the error in the initial guess of ρ_0. Then the computed value of ρ_n is obtained from;

$$Ln\,(\rho_n) = Ln\,(\rho_0 + e_0) - Ln\,(\frac{T_n}{T_0}) - \frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dZ$$

$$\rho_n = (\rho_0 + e_0)\,(\frac{T_0}{T_n})\,Exp\,(-\frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dZ)$$

The percentage error is given by:

$$\%\ Error = \frac{|\rho_{n\ True} - \rho_{n\ Comp}|}{\rho_{n\ True}} = \frac{e_0\,(\frac{T_0}{T_n})\,Exp\,(-\frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{K}\, dZ)}{\rho_0\,(\frac{T_0}{T_n})\,Exp\,(-\frac{1}{K}\int_{Z_0}^{Z_n} \frac{|g|}{T}\, dZ)}$$

$$\%\ Error = \frac{e_0}{\rho_0}$$ a constant for the entire flight.

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Wright, John B. and John J. Graham, Jr. "BALLUTE Retardation Device for Meteorological Rocketsondes." Goodyear Aerospace Corporation, Akron, Ohio. 1966, AFCRL-65-877.

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13. ABSTRACT

Experimental tests have been made with various configurations of the BALLUTE in order to develop a stable retardation device for meteorological rocketsondes. This report discusses the reduction and analysis of these tests. Several of the BALLUTE configurations are shown to satisfy the project goal of providing the required stability as well as a sufficiently slow fall velocity to accurately measure winds and temperature.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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